PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 4043PTWO/er	**FOR FURTHER ACTION**	See Form PCT/IPEA/416
International application No. PCT/IB2004/001022	International filing date *(day/month/year)* 24.03.2004	Priority date *(day/month/year)* 25.03.2003
International Patent Classification (IPC) or national classification and IPC B23K11/04, B23K11/24, G05B13/04, B23K11/25		
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1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 9 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:
   a. ☒ *sent to the applicant and to the International Bureau)* a total of 8 sheets, as follows:
      ☒ sheets of the description, claims and/or drawings which have been amended and are the basis of this report and/or sheets containing rectifications authorized by this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions).
      ☒ sheets which supersede earlier sheets, but which this Authority considers contain an amendment that goes beyond the disclosure in the international application as filed, as indicated in item 4 of Box No. I and the Supplemental Box.
   b. ☐ *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) , containing a sequence listing and/or tables related thereto, in computer readable form only, as indicated in the Supplemental Box Relating to Sequence Listing (see Section 802 of the Administrative Instructions).

4. This report contains indications relating to the following items:

☒	Box No. I	Basis of the opinion
☐	Box No. II	Priority
☐	Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
☐	Box No. IV	Lack of unity of invention
☒	Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
☐	Box No. VI	Certain documents cited
☐	Box No. VII	Certain defects in the international application
☒	Box No. VIII	Certain observations on the international application

Date of submission of the demand	Date of completion of this report
20.01.2005	23.03.2005
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Jeggy, T Telephone No. +49 89 2399-7341

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

International application No.
PCT/IB2004/001022

Box No. I Basis of the report

1. With regard to the **language**, this report is based on the international application in the language in which it was filed, unless otherwise indicated under this item.

   ☐ This report is based on translations from the original language into the following language , which is the language of a translation furnished for the purposes of:
   - ☐ international search (under Rules 12.3 and 23.1(b))
   - ☐ publication of the international application (under Rule 12.4)
   - ☐ international preliminary examination (under Rules 55.2 and/or 55.3)

2. With regard to the **elements*** of the international application, this report is based on *(replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report)*:

Description, Pages

1-5, 7, 10-15	as originally filed
6, 6a, 8, 9, 9a	received on 25.01.2005 with letter of 20.01.2005

Claims, Numbers

1-9	received on 25.01.2005 with letter of 20.01.2005

Drawings, Sheets

1-3	as originally filed

☐ a sequence listing and/or any related table(s) - see Supplemental Box Relating to Sequence Listing

3. ☐ The amendments have resulted in the cancellation of:
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

4. ☒ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).
   - ☐ the description, pages
   - ☒ the claims, Nos. 1,6
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

* *If item 4 applies, some or all of these sheets may be marked "superseded."*

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

International application No.
PCT/IB2004/001022

Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-9
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-9
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-9
	No:	Claims	

2. Citations and explanations (Rule 70.7):

see separate sheet

Box No. VIII Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

see separate sheet

Re Item I
Basis of the report

I.1 The amendments filed with the letter dated 20.1.2005 introduce subject-matter which extends beyond the content of the application as filed, contrary to Article 34(2)(b) PCT. The amendments concerned are the following :

I.2 The applicant has defined in claim 1, that the dynamic state observer estimates, by means of a mathematical model, the trend of a plurality of state variables and of performance variables, the latter comprising at least the arc length. Such a disclosure, that the performance variables comprise at least the arc length, is never disclosed alone in all the application as originally filed. From the description (page 6, lines 31-33), that the control system controls, during the scintillation step not only the arc impedance but also a plurality of other variables, amongst which, in the first place, the arc length. From such a formulation, it is clear that the control system will at least control two performance variables, i.e. the arc impedance and the arc length. It is also clear from originally filed claim 3, that the performance variables controlled by the dynamic control law comprises arc impedance, arc length and primary voltage.

In the present International Preliminary Examination Report, claim 1 is examined with the subject-matter of originally filed claim 1 wording (see also Item VIII.1).

1.3 The applicant has defined in claim 6 a dynamic path observer for performance variables, adapted for defining predetermined optimal paths for the performance variables to follow, the latter comprising at least the arc length. For the same reasons as those detailed in Item 1.2, claim 6 does not fulfil the requirements of the PCT with respect to Article 34 (2) PCT.

Re Item VIII
Certain observations on the international application

VIII.1 Claims 1 and 6 are not clear (Article 6 PCT), as an essential feature for both the method and the apparatus claims is not yet defined in these two claims, in order to solve the problem identified by the applicant. Indeed, as stated in the description

(page 6, lines 31-33) and claim 3, in order to eliminate the problems of the previous similar methods and apparatuses and to obtain optimal results, the control system according to the present invention should control not only the arc impedance but also a plurality of other variables, amongst which, in the first place, the arc length. Further in claim 3, it is clear that the optimal list of performance variables to be controlled comprises arc length, arc impedance and primary voltage of arc current.

This complete list of performance variables as originally defined in claim 3 should be introduced in the subject-matter of claims 1 (method) and 6 (apparatus), so that the requirements of the PCT with respect to Article 6 PCT are fulfilled.

Further, claim 1 defines that said dynamic state observer estimates the trend of a plurality of state variables and performance variables using a plurality of direct measurements. But no implicit step for the measurement is defined in claim 1 and no measurement means is defined in claim 6 in order to supply the dynamic state observer with such measurements. This has to be defined in claims 1 and 6, so that the requirements of the EPC with respect to Article 6 PCT are fulfilled.

Further, claim 6 is not clear (Article 6 PCT). Indeed, claim 6 defines that the system for controlling a butt welding machine comprises a dynamic state observer. The latter are adapted for observing a plurality of state variables of the welding process carried out by the machine. From such a definition, it is not clear which functions are really achieved by this state observer. It is clear form the description (pages 10, lines 7-23) and claim 1, that the dynamic state observer is for estimating through mathematical model the trend of a plurality of state variables and of performance variables using the plurality of direct measurements. This clear and precise function of the dynamic state observer has to be defined in claim 6.

VIII.2 In the present communication, claims 1 and 6 are examined with the following wording (see Items V.2 and V.3) :

Cl 1: A method for on-line control of a butt-welding machine of the flash welding type for bars, blooms or billets during welding cycles comprising the steps of :

a- measuring on the machine by an acquisition system direct measurements
b- controlling an actuation of a valve controlling the positioning of clamps of the welding machine
c- controlling the triggering angle of a partialiser for controlling the thermal power supplied to the welding process, said controlling steps being regulated on the basis of an analysis by a dynamic state observer of the history of the welding process during execution of each welding cycle

characterised by the fact that said dynamic state observer estimates, by means of a mathematical model, the trend of a plurality of state variables and performance variables, the latter comprising arc impedance, arc length and primary voltage of arc current, used as a basis for controlling the welding cycle and the subsequent welding cycles, using the plurality of direct measurements made by the acquisition system.

Cl 6 : a system for controlling a butt-welding machine for bars, blooms or billets, wherein the machine comprises a valve for controlling positioning of the clamps of the machine and a partialiser, wherein the control system is adapted to perform the method according to claim 1, and comprising :

a- an acquisition system for realising direct measurements on the machine
b- a dynamic state observer and a dynamic path generator for performance variable, both for estimating through mathematical model implemented therein the trend of a plurality of state variables and of performance variables, the latter comprising arc impedance, arc length and primary voltage of arc current, using the plurality of direct measurements in order to define predetermined optimal paths for the performance variables to follow
c- a dynamic control law adapted for controlling the valve and the partialiser on the basis of the value of the performance variables and on the optimal predetermined paths
d- a generator of sync signals adapted for generating sync signals

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

V.1 Cited documents

Reference is made to the following documents :

D1: US-A-3 612 811 (FAV.S. LIFSHITS ET AL) 12 October 1971 (1971-10-12)
D2: EP-A-1 044 753 (MATSUSHITA ELECTRIC IND CO LTD) 18 October 2000

(2000-10-18)

D3: EP-A-1 193 020 (COCKERILL RECH & DEV) 3 April 2002 (2002-04-03)

D4: US-A-4 940 876 (BONDARUK ANDREI V ET AL) 10 July 1990 (1990-07-10)

D5: PATENT ABSTRACTS OF JAPAN vol. 015, no. 164 (M-1106), 24 April 1991 (1991-04-24) & JP 03 032474 A (KAWASAKI STEEL CORP), 13 February 1991 (1991-02-13)

D6: GALANTUCCI L M: "COMPUTER-AIDED DESIGN FOR FLASH WELDS" WELDING INTERNATIONAL, WELDING INSTITUTE. ABINGTON, GB, vol. 8, no. 3, 1994, pages 195-204, XP000429686 ISSN: 0950-7116

V.2 Claims 1-5

Document D1, which is considered to represent the most relevant state of the art, discloses (the references in parentheses applying to this document) a method for on-line control of a butt-welding machine 81 ; Figure 1) of the flash welding type for bars (2, 2' ; Column 1, lines 4-7) during welding cycles from which the subject-matter of claim 1 differs through the steps defined in the characterising portion (see Item VIII.2).

The problem to be solved by the present invention may therefore be regarded as to provide a method of on-line controlling a butt-welding with higher accuracy.

The solution to this problem proposed in claim 1 of the present application is considered as involving an inventive step (Article 33 (3) PCT) for the following reasons :

a- D1 is using detectors located on the vinicity of the welding zone. No indication could be found in D1 to control the welding process through use of mathematical models so that the trend of performance variable could be estimated. By this estimation, the controller could act on the machine in order to correct some of the welding parameters. The use of such a mathematical model allows a higher accuracy for piloting the welding machine. D2 describes the use of particular mathematical models for resistance spot welding, i.e. a total different welding process with also different essential parameters. D4 discloses

a flash butt welding wherein the welding process is controlled on basis of the arc impedance only, so that a low accuracy on the control is achieved.

b- These distinguishing steps cannot be found in the other documents cited in the international search report

Claims 2-5 are dependent on claim 1 and as such also meet the requirements of the PCT with respect to novelty and inventive step (Article 33 (2-3) PCT).

V.3 Claims 6-9

Document D1, which is considered to represent the most relevant state of the art, discloses (the references in parentheses applying to this document) a system for controlling a butt-welding machine for bars, blooms or billets, wherein the machine comprises a valve for controlling positioning of the clamps of the machine and a partialiser, wherein the control system is adapted to perform the method according to claim 1 from which the subject-matter of claim 6 differs in that the system further comprises :

a- a dynamic state observer and a dynamic path generator for performance variable, both for estimating through mathematical model implemented therein the trend of a plurality of state variables and of performance variables, the latter comprising comprising arc impedance, arc length and primary voltage of arc current, using the plurality of direct measurements in order to define predetermined optimal paths for the performances variables to follow

b- a dynamic control law adapted for controlling the valve and the partialiser on the basis of the value of the performance variables and on the optimal predetermined paths

The problem to be solved by the present invention may therefore be regarded as to provide a method of on-line controlling a butt-welding with higher accuracy.

The solution to this problem proposed in claim 6 of the present application is considered as involving an inventive step (Article 33 (3) PCT) for the same reasons as those detailed for claim 1 (see Item V.2).

Claims 7-9 are dependent on claim 6 and as such also meet the requirements of the PCT with respect to novelty and inventive step (Article 33 (2-3) PCT).

hydraulic position control. The short-circuit impedance, which is an essential parameter in the system of calculation adopted, is measured and re-updated, in the upsetting step, at the end of each welding cycle. In this way, this control system does not, however, take into account in any way the fact that the characteristic of the arc in the initial moments of the welding process varies enormously and hence does not remain constant in the course of a welding cycle. This variation occurs because, especially in the presence of irregular end surfaces, the electric arc starts first in one point of the joints where these are set closer to one another and is then widened progressively to the rest of the end surface, employing, however, a few seconds to involve the entire joint. In order to maintain the arc impedance constant in this step in the presence of an arc that changes characteristic, the said control system is unable to prevent short-circuits from being formed during ignition. Since at each short-circuit there is an extinction of the arc and hence a reduction in the thermal energy supplied to the joints, this type of controller produces irregularities in the energy supplied to the weld, and hence there is a dispersion of the results.

Document US-A-3612811 discloses a method of effecting electrical butt-welding of workpieces by continuously flashing the ends of the workpieces. The apparatus for welding control is provided with two channels one of which comprises two temperature pickups. A computer, based on these inputs, controls an actuator for moving the workpieces in the course of the flashing process.

Summary of the invention

The main purpose of the present invention is to eliminate the disadvantages cited, according to a first aspect of the invention, by means of a method for controlling a butt-welding machine of the "flash-welding" type according to Claim 1 and, according to a second aspect of the invention, by means of a control system with the characteristics of Claim 3.

A diagnostics system according to the present invention, by acting simultaneously on the variable parameters that intervene in the various steps of the welding operation, is able to optimize the results of said operation.

In particular, the present invention overcomes problems left unresolved by known controllers and, in particular, by the impedance controller described in US-A-

4940876 mentioned previously, which, amongst controllers, constitutes one of the more advanced embodiments but which does not act on the supply voltage to improve the welding control.

In order to obtain optimal results, the control system according to the invention controls, during the scintillation step, not only arc impedance but also a plurality of other variables, amongst which, in the first place, the arc length. Thanks to this

The combination of all these elements, envisaged in the control system according to the invention, determines the superior weld quality in the billets.

Amongst the main purposes that the control system makes possible, there is that of rendering more reliable and repetitive, in each step of the welding operation, the trend of the electrical, thermal and mechanical state variables of the welding system, as well as that of possibly not allowing any joints in which the welding operation has not been altogether successful to move on for the subsequent processing steps.

List of figures

Further advantages that may be achieved with the present invention will emerge more clearly to a person skilled in the art from the ensuing detailed description of a particular and non-limiting embodiment of a system for on-line control of a butt-welding machine with reference to the following figures, in which:

Figure 1 is the block diagram of the control system according to the invention;

Figure 2 is the functional logic diagram of the method according to the invention; and

Figure 3 presents a number of graphs with optimal paths of some performance variables.

Detailed description of the invention

The solution according to the invention for solving the technical problem provides for a method for control and on-line diagnosis of a butt-welding machine of the "flash-welding" type, adapted to be included in a continuous process for the fabrication of blooms and billets.

The method according to the invention substantially envisages controlling, on the basis of pre-determined criteria illustrated in greater detail in the ensuing description, two actuators that act respectively on the angle of triggering of the partializer for controlling the electric machine that supplies the thermal power to the weld and on the opening of the valve that controls positioning of the clamps of the welding machine.

With particular reference to Figure 1, in which the following symbols are used:

U = control signals (transformation rate, triggering angle, valve switch);

Ym = direct measurements (AC power, AC voltage, current, voltage DC, outlet

temperature, inlet temperature, cylinder position, valve position, cylinder pressure);

Z = performance variables;

Z_{set} = desired paths of Z;

Z_{spec} = specifications of the paths of Z;

X = estimated state variables;

Sync = state of the welding sequence; and

Y_{diag} = diagnostic alarms,

the method according to the invention is implemented via a control system comprising a multivariable dynamic control law, block C, based upon techniques of multi-objective optimization and of robust synthesis capable of maintaining under accurate control all the paths of the variables that determine the quality of the process, even in conditions where there is uncertainty on the parameters that define the characteristic of the arc and the geometry of the joints, so as to cause the trends of all the electrical, mechanical and thermal quantities to converge rapidly, right from the start of the welding operation, towards the desired values, notwithstanding the occurrence of wide parametric variations in the course of the welding process.

According to a particularly advantageous aspect of the invention, the control system also envisages a diagnostics system capable of identifying the joints that it had not been possible to weld correctly on account of the presence of extreme values of the disturbance phenomena.

The dynamic control law, block C, acts simultaneously on the angle of triggering of a partializer, which regulates the supply, and on the hydraulic control of movement of the clamps by maintaining the real trend of the electrical, mechanical and thermal values of the welding process close to the optimal trend. Since not all the variables that determine the trend of the welding process can be measured, there is provided a method of estimation based upon a mathematical and heuristic model that reconstructs on line the variables necessary for completing the information on the state of the weld. On the basis of these state variables, the variables that determine the quality of the process are identified, the trend of which determines the goodness of the global result of the weld. For these variables, which we shall call "performance variables", through tests, the optimal paths that

should be followed during the welding operation have been determined.
On the basis of the performance variables supplied by a dynamic state observer there has been developed also a diagnostics system capable of detecting whether

NEW CLAIMS

1. A method for on-line control of a butt-welding machine of the flash-welding type for bars, blooms or billets, during welding cycles, comprising the steps of

- controlling an actuation of a valve controlling positioning of clamps of the welding machine; and

- controlling the triggering angle of a partializer for controlling the thermal power supplied to the welding process;

said controlling steps being regulated on the basis of an analysis by a dynamic state observer (A) of the history of the welding process during execution of each welding cycle, characterised by the fact that said dynamic state observer (A) estimates, by means of a mathematical model, the trend of a plurality of state variables (X) and of performance variables (Z), the latter comprising at least the arc length, used as basis for controlling the welding cycle itself and the subsequent welding cycles, using a plurality of direct measurements (Ym).

2. The method according to Claim 1, wherein for regulating said controlling steps there is provided:

- observing state variables (X) of the welding cycles by the dynamic state observer (A);

- defining pre-determined optimal paths (Z_{set}) to be followed by a plurality of performance variables (Z) by means of a dynamic path generator (B) for performance variables (Z);

- executing a dynamic control law (C) based upon the value of the performance variables (Z), of the optimal paths (Z_{set}) and of an operating strategy determined

according to the step that the welding process is undergoing; and

- generating sync signals (Sync) by means of a signal generator (E), on the basis of which the dynamic control law (C) adopts the given operating strategies.

3. The method according to Claim 2, wherein the dynamic control law (C), during a scintillation step of the welding process, maintains the arc length constant and varies the primary voltage on the basis of the variation of arc impedance.

4. The method according to Claim 3, wherein an on-line diagnosis is provided by a dynamic diagnostics system (D), for which the comparison of the paths of the performance variables (Z) is made with the desired paths (Z_{set}) by said dynamic diagnostics system (D), generating weld quality indices.

5. The method according to Claim 6, wherein there is provided automatic on-line variation of the transformation ratio of a transformer (tap changing) for supply of the butt-welding machine.

6. A system for controlling a butt-welding machine for bars, blooms or billets, wherein the machine comprises a valve for controlling positioning of clamps of the machine, and a partializer, wherein the control system is adapted to perform the method according to claim 1 and comprises:

- a dynamic state observer (A) adapted for observing a plurality of state variables (X) of a welding process carried out by said machine;
- a dynamic path generator (B) for performance variables (Z), adapted for defining pre-determined optimal paths (Z_{set}) for the performance variables (Z) to follow, the latter comprising at least an arc length;
- a dynamic control law (C) adapted for controlling the valve and the partializer on the basis of the value of the performance variables (Z) and of the optimal pre-

determined paths (Z_{set}); and

- a generator (E) of sync signals adapted for generating sync signals (Sync).

7. The system according to Claim 6, wherein there is provided a transformation ratio variator (tap changer), adapted for controllling the transformation ratio.

8. The system according to Claim 7, wherein a dynamic diagnostics system (D) is provided, adapted for generating indices of weld quality, comparing the paths of the performance variables (Z) with the desired paths (Z_{set}).

9. The system according to Claim 8, wherein the observer (A) of dynamic state, the dynamic path generator (B), the dynamic control law (C), the generator of sync signals (E), and the dynamic diagnostics system (D) are implemented by means of a computer program.